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Peter D Persans

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14. ABSTRACT

This is a final report on an experimental research program to characterize the optoelectronic properties of very heavily sulfur doped silicon (also known as “Black Silicon”) in close collaboration with scientists at US Army Benet Labs, Harvard, and the Army Research Laboratories. Materials and devices will be prepared at Harvard. The thrusts of the proposed work were: i) to elucidate the origin of excess infrared absorption and to determine how this absorption contributes to photoresponse, and ii) to measure the transport properties of photoexcited charge

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Report Title

Optical and Photoconductive Characterization of Black Silicon

ABSTRACT

This is a final report on an experimental research program to characterize the optoelectronic properties of very heavily sulfur doped silicon (also known as "Black Silicon") in close collaboration with scientists at US Army Benet Labs, Harvard, and the Army Research Laboratories. Materials and devices will be prepared at Harvard. The thrusts of the proposed work were: i) to elucidate the origin of excess infrared absorption and to determine how this absorption contributes to photoresponse, and ii) to measure the transport properties of photoexcited charge carriers.

By analyzing the photoconductivity and photoresponse of coplanar and diode devices we were able to set limits on the mobility-lifetime product of sulfur-hyperdoped material. We have proposed an excitation and charge separation mechanism that is consistent with all data.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
01/06/2012	2.00	Nathaniel E. Berry, Daniel Recht, Peter D. Persans, David Hutchinson, Aurore J. Said, Jeffrey M. Warrender, Hannah Peterson, Anthony DiFranzo, Christina McGahan, Jessica Clark, Will Cunningham, Michael J. Aziz. Photocarrier Excitation and Transport in Hyperdoped Planar Silicon Devices, MRS Proceedings, (7 2011): 0. doi: 10.1557/opl.2011.1150
01/06/2012	1.00	Aurore J. Said, Daniel Recht, Joseph T. Sullivan, Jeffrey M. Warrender, Tonio Buonassisi, Peter D. Persans, Michael J. Aziz. Extended infrared photoresponse and gain in chalcogen-supersaturated silicon photodiodes, Applied Physics Letters, (01 2012): 0. doi: 10.1063/1.3609871
08/01/2012	5.00	David Hutchinson, Thomas Cruson, Anthony DiFranzo, Andrew McAllister, Aurore J. Said, Jeffrey M. Warrender, Daniel Recht, Peter D. Persans, Michael J. Aziz. Contactless Microwave Measurements of Photoconductivity in Silicon Hyperdoped with Chalcogens, Applied Physics Express, (03 2012): 41301. doi: 10.1143/APEX.5.041301
12/12/2012	7.00	Peter D. Persans, Nathaniel E. Berry, Daniel Recht, David Hutchinson, Hannah Peterson, Jessica Clark, Supakit Charnvanichborikarn, James S. Williams, Anthony DiFranzo, Michael J. Aziz, Jeffrey M. Warrender. Photocarrier lifetime and transport in silicon supersaturated with sulfur, Applied Physics Letters, (09 2012): 111105. doi: 10.1063/1.4746752
TOTAL:	**4**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Mapping photoresponse in black silicon diodes, Chris Fuller, D. Hutchinson, A DiFranzo, D. Recht, A. Said, J. Warrender, P. Persans, Black Silicon Workshop, Albany NY Aug 2010.

Optoelectronic characterization of sulfur-hyperdoped silicon-on-insulator films, P. Persans, J. Warrender, H. Peterson, N. Berry, A. DiFranzo, J. Clark, D. Elton, D. Recht, Black Silicon Workshop, Albany NY Aug 2010.

Photoconductivity in Coplanar Black Silicon, C. McGahan, N. Berry, C. Fuller, J. Cotter, P. Persans, Black Silicon Workshop, Albany NY Aug 2010.

Photocarrier excitation and transport in sulfur-hyperdoped silicon devices, P. Persans, D. Recht, D. Hutchinson, A. Said, J. Warrender, N. Berry, A. DiFranzo, J. Clark, C. McGahan, Black Silicon Workshop, Cambridge MA April 2011.

Photocarrier Excitation and Transport in Hyperdoped Planar Silicon Devices, Peter D. Persans1, Nathaniel Berry1, Daniel Recht2, David Hutchinson1, Aurore Said2, Jeffrey Warrender3, Hannah Peterson1,3, Anthony DiFranzo1, Christina McGahan1, Jessica Clark1, Will Cunningham1, Michael Aziz2, MRS Symposium A Poster, April 2011.

Photoresponse of coplanar sulfur-hyperdoped silicon-on-insulator layers, J. Clark, P. Persans, J. Warrender, D. Recht, Black Silicon Workshop, Albany NY Aug 2009.

Transient Photoresponse in Coplanar Black Silicon Devices, N. Berry, A. DiFranzo, P. Persans, D. Recht, Black Silicon Workshop, Albany NY Aug 2009.

Number of Presentations: 7.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received	Paper	
08/01/2012	6.00	Peter D. Persans, Nathaniel E. Berry, Daniel Recht, David Hutchinson, Hannah Peterson, Jessica Clark, Supakit Charnvanichborikarn, James S. Williams, Anthony DiFranzo, Michael J. Aziz, Jeffrey M. Warrender. Photocarrier Lifetime and Transport in Silicon Supersaturated with Sulfur, Applied Physics Letters (04 2012)

TOTAL: **1**

Number of Manuscripts:

Books

Received	Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
David Hutchinson	0.20	
Thomas Cruson	0.20	
Brett Spencer	0.00	
FTE Equivalent:	**0.40**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Peter Persans	0.05	
FTE Equivalent:	**0.05**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
David Lombardo	0.10	Physics
Nathaniel Berry	0.20	Physics
Anthony DiFranzo	0.20	Physics
Andrew MacAllister	0.10	Physics
CHris Fuller	0.10	Industrial and Systems Engineering
Drew Rosen	0.10	Physics
FTE Equivalent:	**0.80**	
Total Number:	**6**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 6.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields: 6.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields: 6.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale): 6.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering: 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 6.00

Names of Personnel receiving masters degrees

NAME
David Hutchinson
Brett Spencer
Thomas Cruson
Total Number: 3

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

The goal of the proposed work was to measure and elucidate photocarrier excitation and recombination processes and parameters in heavily doped S:Si prepared by implantation and pulsed laser melting. Fundamental parameters such as free carrier diffusion lengths, mobility, drift mobility, free carrier lifetime, and decay time were to be extracted from photoconductivity, steady state photocarrier grating, and photoresponse measurements.

We developed techniques for measurement and analysis of coplanar photoconductivity response spectra for the extraction of minority carrier diffusion lengths and photocarrier lifetimes in thin layers. This allowed us to set limits on the carrier mobility and lifetimes in Si hyperdoped with chalcogens.

We characterized the photodetection efficiency spectral response of n+/p diodes based on S-hyperdoped Si and established that normal response is due to carriers generated in the depletion region in the normally doped Si substrate. The hyperdoped region creates a good-quality high-conductivity contact layer and a rectifying junction with the substrate. Collection efficiency in the near infrared is of order 0.5, dropping off dramatically beyond 1100 nm wavelength.

We observed very high gain photoresponse in regions of some diode devices based on n+/p junctions. The current working model is that high gain is due to modification of the n+/p barrier by trapped photocarriers, allowing majority carriers from the p-region to to flow through the junction. Further work is underway to identify the origin, reproducibility, and utility of this high gain behavior.

We developed a photoresponse mapping system that enabled us to identify the scope of high gain regions.

We developed techniques for measuring optical absorptance in thin layers using photothermal deflection spectroscopy and were able to confirm that transmission and spectroscopic ellipsometry measurements of IR absorption in hyperdoped layers were reliable.

We developed contactless microwave and contacted coplanar techniques to measure transient photoconductivity of n+/p and n+ SOI layers. Initial results confirmed lifetimes inferred from steady state measurements. Recent measurements in collaboration with Jeff Warrender at Benet Labs indicate that we will be able to directly measure lifetimes for UV and IR excitation of thin layers hyperdoped with S, Se, Au, Ti, and other novel dopants.

In addition our specific published work to measure general properties of hyperdoped materials, we performed regular characterization of hundreds of new materials and devices fabricated at Benet Laboratories and Harvard University with assistance from the Buonassissi group at MIT.

Our observation of high gain in S:Si and Se:Si based n+/p diodes led to an increased focus on these devices. A preliminary paper has been published in Applied Physics Letters. The analysis of the spatial size, voltage dependent gain, and wavelength dependent response including 5 micron-scale resolution maps has formed the basis for an MS thesis.

The project was led by Prof. Peter Persans. Three graduate students participated in this project resulting in two MS projects (Thomas Cruson and Brett Spencer) and one MS thesis (David Hutchinson). David Hutchinson is continuing to work on an extension of this project for his PhD thesis. A fourth MS student, Colonel Alex Katauskas, will complete his degree work in May 2013. Colonel Katauskas will take up a position at West Point after completing his work with us. We expect that he will continue to collaborate with us while he is posted at West Point.

Aurora Said and Daniel Recht of Harvard University and Jeff Warrender of ARDEC spent several days each in our laboratories carrying out measurements.

Several undergraduate students participated in this project, including senior students Nathaniel Berry, Nikolina Bohr , Jessica Clark, Anthony DiFranzo, Andrew McAllister, Christina McGahan, and Hanna Peterson, and junior students James Cotter, William Cunningham, Chris Fuller, James Ladouce, Mark Millman, Drew Rosen, and David Lombardo. Although this contract supplied partial support for many of these students, significant funding was provided by the NSF REU program, the NSF GK12 program, and the Graduate Teaching Assistantship and Undergraduate Research programs at Rensselaer.

Technology Transfer